Evolution of Tropical Cyclone Characteristics and Forecast Assessment

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LONG-TERM GOALS

A long-term goal is to understand how variabilities in the environment and internal tropical cyclone structure influence tropical cyclone track and intensity characteristics and how these influence differ between developing, mature, and decaying tropical cyclones. During the initial stages of tropical cyclone development, structure and track characteristics can exhibit large variabilities that pose difficult forecast situations. Because decaying tropical cyclones often transition to fast-moving and rapidly-developing extratropical cyclones that may contain gale- or storm-force winds, special attention is given to improving understanding and prediction of the extratropical transition phase of a decaying tropical cyclone. Therefore, a tropical cyclone throughout its life cycle has the potential for impacting many fleet components. As increased understanding leads to improved forecasts of tropical cyclone motion and structure characteristics, a long-term goal of this project is to assess the utility of the tropical cyclone forecast products to shore- and sea-based assets.

OBJECTIVES

The evolutions of tropical cyclone motion and structure characteristics depend on a variety of environmental and internal factors. The primary objective of this research is to identify these factors and determine how they impact tropical cyclone features. For example, it has been hypothesized that the outer wind structure of the mature tropical cyclone, which is important to understanding its motion over shorter time scales, is dependent on the growth, evolution, and decay characteristics of mesoscale convective systems (MCSs) and associated midlevel vortices. Therefore, one objectives is to improve understanding of factors that control MCS evolution in the tropical cyclone environment, and of the relationships between MCS development and the large-scale environment throughout the entire tropical cyclone life cycle, which includes developing, mature, decaying, and extratropical transition.

Increased understanding of the influences on tropical cyclone characteristics that are sought as an objective of this research is important because of their effect on forecast operations, which must provide appropriate warning to fleet units concerning impacts from tropical cyclone-related conditions. Therefore, another objective of this research is to assess the utility of tropical cyclone forecasts in relation to fleet operations. A description of forecast value in the context of fleet

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utility provides a metric that allows assessment of the impacts on forecast operations due to increased understanding of factors that influence tropical cyclone characteristics. Also, deficiencies in forecast utility may identify those environmental conditions that require further understanding to impact the forecast process in a positive manner.

APPROACH

The long-term goals and objectives of this research are structured such that a varied suite of technical approaches is required to adequately analyze important tropical cyclone characteristics, factors affecting these characteristics, and the value assigned to forecasts of these characteristics.

Based on initial studies of the influence of mesoscale structures on developing and mature tropical cyclones, it has been hypothesized that the outer wind structure, which may affect its short-term motion, may be determined by conditions at the time of formation. This hypothesis implies that wind structure changes evolve from conditions at formation time and that these developments (excluding drastic external influences) are small compared to structural characteristics that are established during formation. Results of the initial studies implied that the primary characteristics that influence the wind structure at maturity are the relative roles of the synoptic-scale circulations and individual MCSs. A major limitation to refinement of the roles played by MCS activity is the lack of data. Therefore, detailed structural characteristics that may define when and how MCS activity could be related to tropical cyclones are difficult to identify. The use of passive microwave observations from the Special Sensor Microwave Imager (SSM/I) on polar-orbiting satellites is one way to overcome this deficiency. However, SSM/I observations are only available when the satellite passes over the target MCS. To observe MCS life-cycle stages in a continuous manner, hourly visible and infrared imagery from geostationary satellites are required. The approach in this research has been to objectively track MCSs in the geostationary imagery and then use combinations of polar-orbiter microwave and geostationary infrared data to define MCS structural characteristics such as convective and stratiform cloud amounts, percent coverage, and rain rates. Furthermore, co-located microwave and infrared imagery are used to calibrate the infrared imagery, which allows for hourly estimates of these parameters to be defined from subsequent infrared images throughout the lifetime of the MCS. The infrared imagery is re-calibrated each time a co-located microwave image is available.

As a tropical cyclone moves poleward, it may transition into an intense midlatitude cyclone that often contains gale- or storm-force winds. These potentially dangerous storms pose a serious threat to shore and maritime assets over midlatitude regions during seasons when extreme cyclonic activity does not normally occur. Therefore, it is logical to extend the study of tropical cyclone characteristics to this stage. For this component of the research, the approach is to assess the impact of various factors such as the evolving internal tropical cyclone features (e.g., convective activity, inner-core structure), midlatitude circulation into which the tropical cyclone is moving, and relative roles of upper- and lower-level processes on the transition from a tropical to an extratropical cyclone. Furthermore, these impacts are also examined with respect to the numerical model forecasts of extratropical transitions.

Definition of the utility of a forecast concerning the impact of tropical cyclone conditions on fleet assets is important for evaluating the forecast process and for determining what factors might

provide increased value to the forecast operation. The approach in this research is to apply the methodology of decision analysis to the problem of assessing the potential accuracy of tropical cyclone forecasts as it applies to fleet operations on shore and at sea. Information such as climatological probabilities and conditional probabilities of forecast accuracy, which may depend on the synoptic environment that could be defined by a technique such as the Systematic Approach to Tropical Cyclone Track Forecasting of L. Carr and R. Elsberry, are input to a statistical model to define threshold values where optimal actions are defined based on minimization of a cost function.

WORK COMPLETED

Co-located SSM/I and geostationary infrared data have been processed for several periods of MCS activity that were related to tropical cyclone evolution. For comparison, similar data were processed for periods of MCS activity not related to tropical cyclone activity.

Based on a multivariate statistical classification of midlatitude circulation patterns, characteristic types of extratropical transitions have been identified. Detailed analyses were completed of the internal and environmental influences on the transitioning tropical cyclone and on the eventual extratropical cyclone that results from the transition process.

A basic statistical model was formulated for assessing forecast value when a decision under uncertainty must be made as to either take action or not take action in terms of protecting assets.

RESULTS

Co-located microwave and geostationary imagery were used to compile a detailed analysis of the evolution of Super Typhoon Bing (September 1997) in terms of the evolution of MCS activity over a several day period (Milot 1998). During this time, a series of five MCSs were tracked and analyzed in terms of their convective and stratiform cloud coverages, and rain intensities associated with each cloud type. Two basic characteristics were defined that related the longevity of the MCS and the evolution of the stratiform component as the MCS decayed. The initial MCS within the pre-Bing disturbance lived for 60 h and contained a large stratiform region with large rain rates that continued for over 12 h beyond the life of the convective portion of the MCS. Therefore, this MCS appeared to contain favorable structural characteristics for midlevel vortex development, which might influence subsequent MCS activity. New MCS episodes did occur, but new systems contained strong, short-lived convective regions and weak stratiform components. Three days after the dissipation of the initial MCS in the pre-Bing disturbance, an intense MCS formed near the center of a large circulation that had been slowly evolving due to repeated MCS life cycles. This case appeared to be representative of the evolution of a tropical cyclone that forms through mutual interaction of MCS activity and synoptic-scale forcing (Harr et al. 1999).

A similar analysis was applied to a set of large and intense MCSs in the general monsoon trough environment of the western North Pacific, but were not related to any tropical cyclone development. In these cases, convective development was swift with equally rapid decay, in which stratiform cloud coverage and rain intensity decreased in conjunction with the convective

coverage. Therefore, conditions were not favorable for midlevel vortex development and concentrated MCS activity.

As a tropical cyclone moves poleward, the characteristic tropical cyclone structure changes to include large asymmetries in convection and wind distribution. Depending on the interaction between environmental conditions and the internal tropical cyclone structure, the tropical cyclone may dissipate or transition into an extratropical cyclone that may include gale- or storm-force winds, high seas, and significant rainfall. Analysis of these interactions was conducted for several types of transitioning tropical cyclones (Harr et al. 1998a,b). These analyses included use of microwave imagery for assessing the internal structure of the tropical cyclone as it moved into the midlatitudes. Also, the formation of extratropical cyclone structures such as frontal regions were examined for a variety of transition cases. Results define a large variability in the types of transitions that occur over the western North Pacific and this variability is linked to the extremely volatile physical conditions that occur during extratropical transition. Furthermore, when forecast sequences of individual transition cases are examined from the Navy Operational Global Atmospheric Prediction System (NOGAPS), a large variability is also found from one forecast to the next (Harr and Elsberry 1998). It appears that the NOGAPS model is sensitive to the extreme physical attributes associated with extratropical transition and how these conditions are depicted in the initial analysis for each forecast sequence.

A basic statistical model has been defined (Harr et al. 1998c) to examine the concept of assessing forecast value in terms of the basic decision analysis problem of having to choose whether to protect assets under conditions of uncertainty about future events. Preliminary results from a sensitivity analysis conducted with this model indicate that accurate assessments of forecast value are extremely dependent on the utilities (values) that are assigned by operators or decision makers concerning the assets that must be protected. These utilities determine the optimal strategy a decision maker would follow based on known forecast accuracy and the climatological estimate of having tropical cyclone conditions impact a facility. Therefore, inaccurate utility estimates that could be attributed to hidden costs, or an inaccurate categorization of costs could lead to assessments that artificially decrease the estimate of forecast value.

IMPACTS

Establishment of the importance of MCS evolution in determining the tropical cyclone structure leads the forecasters to analyze MCS characteristics in satellite imagery. The work of Milot (1998) was designed to establish the utility of the combination of polar-orbiting and geostationary satellite imagery in deducing MCS and tropical cyclone evolution. A "systematic-approach technique" may provide a more complete categorization in terms of various large-scale and MCS parameters that can eventually be used to predict future wind structure based on the characteristics of the large-scale and mesoscale environment.

In response to optimum-track ship routing factors, summer and early autumn trans-ocean maritime activity is often conducted at higher latitudes to take advantage of the climatologically favorable warm season wind and wave height conditions and significantly shorter route distances. Therefore, accurate forecasts of the intensity and movement of transitioning tropical cyclones

during the warm season is critical. Results of Harr and Elsberry (1998), reveal forecast model sensitivities that may identify instances when large forecast variability might occur.

Identification of the value of forecasts concerning the impact of tropical cyclone conditions on fleet assets will help assess how forecasts might be improved and what physical characteristics need to be better understood to realize increased forecast value.

TRANSITIONS

It is expected that the integrated results of this investigation will be transitioned into a forecast system that JTWC will use to synthesize the contribution of MCS, tropical cyclone structure and motion characteristics over the entire lifecycle of a tropical cyclone.

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